

NJDOT Bureau of Research
QUARTERLY PROGRESS REPORT

Project Title:	A Comparison and Analysis of KA-Band Radar Vs. X-Band Radar			
RFP NUMBER: Project 2007-16	NJDOT RESEARCH PROJECT MANAGER: Edward S. Kondrath			
TASK ORDER NUMBER: 4	PRINCIPAL INVESTIGATOR: Allen Katz			
Project Starting Date: 1/ 1/ 2007 Original Project Ending Date: 12/31/2007 Modified Completion Date:	Period Starting Date: 1/ 1/ 2007 Period Ending Date: 3/31/2007			

Task	% of Total	% of Task this quarter	% of Task to date	% of Total Complete
Literature Search	5%	100%	100%	5%
1. Examine the state of development of Ka-band Radar	10%	70%	70%	7%
2. Prove/disprove Ka-band Radar is as reliable as X-band radar	30%	30%	30%	9%
3. Statistically validate radar testing approaches	25%	20%	20%	5%
4. Develop requirements for Ka- band radar meeting requirements of the Court system	10%	0%	0%	0%
5. Examine the state of development for Laser-band Radar	10%	10%	10%	1%
Final Report	10%	0%	0%	0%
TOTAL	100%			27%

Project Objectives:

1. Examine the state of the art in model development for Ka-band Radar.
2. Prove or disprove that the new technology (Ka-band Radar) is at the least as reliable as the current (X-band radar).
3. Identify data deficiencies and the statistical validity of alternative approaches.
4. Develop requirements and standards for Ka-band radar for all the requirements that are imposed by the Court system to be accepted as an instrument that measures speed.

Added Objectives:

5. Examine the state of the art in model development for Laser-band Radar.

As of 2/06/2004

Project Abstract:

This project focuses on the New Jersey State Police commitment to highway safety by enforcing posted speed limits. Effective enforcement of speeding statutes requires measured speed to be accurate and state of the art. This requirement is necessary in order to successfully prosecute by using both moving and stationary radar.

The New Jersey State Police currently utilizes MPH Industries K55 X-band radar units. The New Jersey courts have taken judicial notice as to the scientific reliability of the K55 radar. The advent of new Ka-band Radar technology now allows smaller and safer radar units to be employed. To successfully utilize these new Ka-band Radar units their speed measurement accuracy must be established in a scientific manner that will be accepted by the New Jersey courts.

This purpose of this research project will be to 1) establish a program for testing the performance of the new Ka-band radar units relative to the present K55 radar, 2) monitor the implementation of this testing program, 3) review the test results, 4) provide conclusions on performance and 5) document these conclusions in a way that will facilitate the employment of Ka-band radar by the New Jersey State Police.

The relative characteristics and performance of available Ka-band radar units will also be investigated and documented.

New and innovative programs like the introduction of the Ka-band radar speed detection devices will enable the Division of State Police to enhance their speed enforcement program to better serve the motorists who travel New Jersey's highways.

1. Progress this quarter by task:

- a) Examine the state of development of Ka-band Radar – A literature search was conducted to determine the state of the art in Ka-band Doppler radar technology. A bibliography generated during this search is contained in Appendix 1 of this report. The front running manufacturers of Ka-band Radar units (Stalker and MPH) were contacted and literature gathered on the technical performance of their models. This material is currently being studied. Both X and Ka-band radar units were inspected by the research team and their operation observed.
- b) Prove/disprove Ka-band Radar is as reliable as X-band radar – A plan for field testing Ka-band radar units produced by Stalker and MPH was formulated. The test documentation plan and measurement procedure was reviewed. 200 measurements were made, under fair, rain and snow weather conditions that compared the performance of a Stalker Ka-band radar unit to an MPH K55 X-band radar unit, and the testing monitored. A study on the effects of weather on Ka-band vs. X-band Doppler Radar performance was also begun.
- c) Statistically validate radar testing approaches – The results of these first tests were statistically analyzed. The results of this analysis are shown in the following figures.

Fig. 1 - PDF Stalker Ka Versus X-band

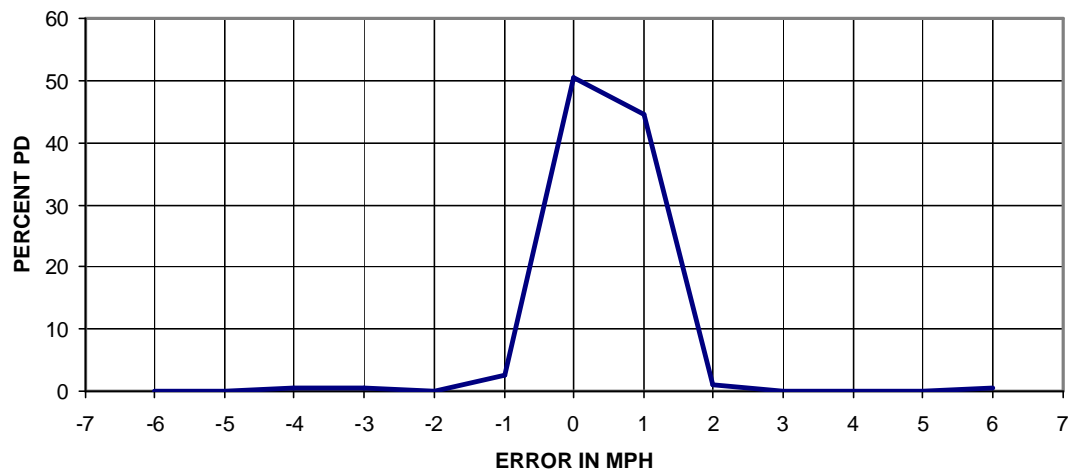
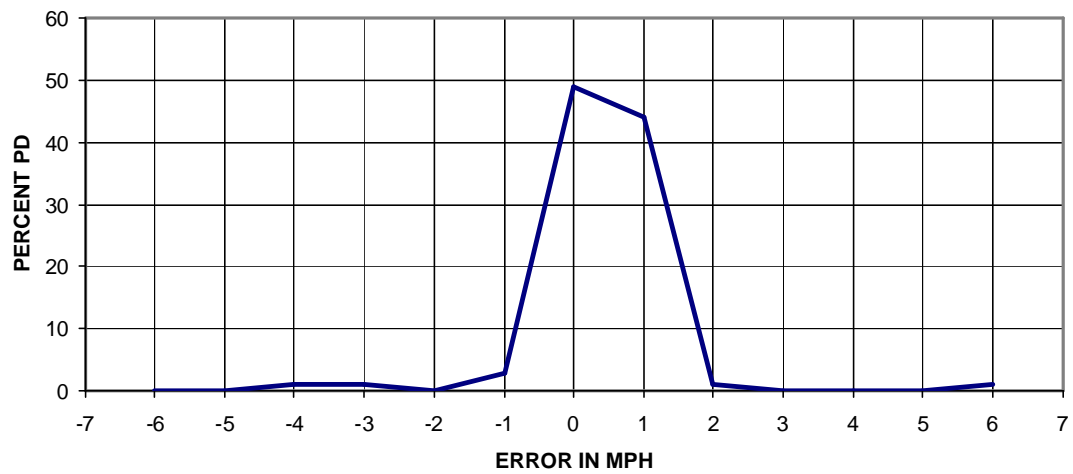
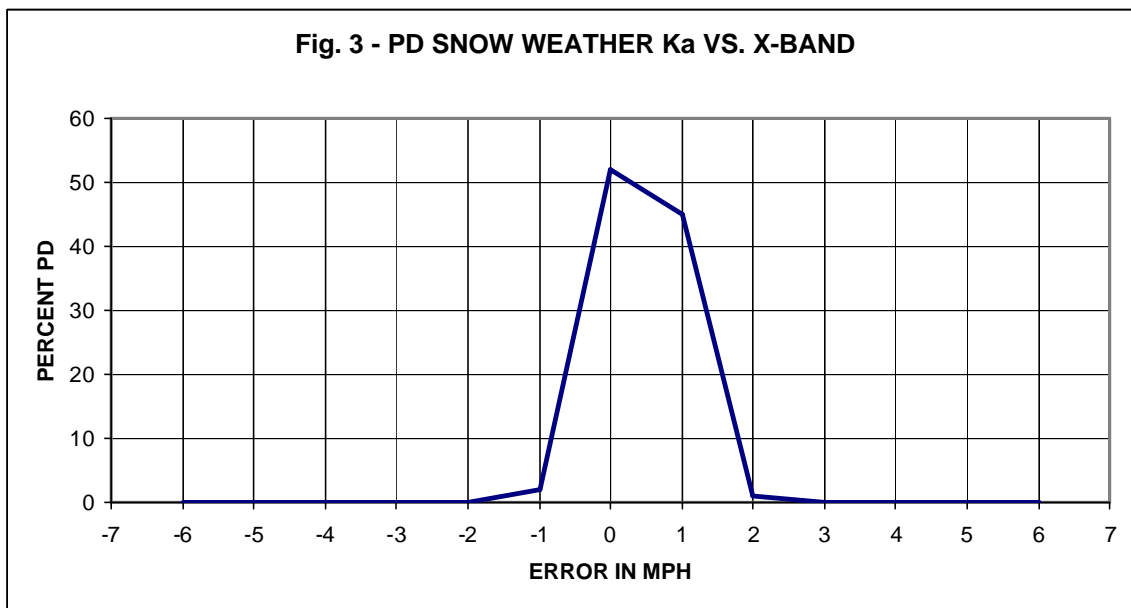


Fig. 2 - PD CLOUDY/WET WEATHER Ka VS. X-BAND





- d) Develop requirements for Ka-band radar meeting requirements of the Court system – No direct progress has been made on this objective.
- e) Examine the state of development for Laser-band Radar -- Laser based radar was added to the literature search and manufactures of laser based radar contacted for technical information.

2. Proposed activities for next quarter by task

- a) Examine the state of development of Ka-band Radar -- The study on the relative technical performance of the front running Ka-band Radar units (Stalker and MPH) should be completed during this quarter.
- b) Prove/disprove Ka-band Radar is as reliable as X-band radar – Addition measurements will be made of the Stalker Ka-band radar unit relative to an MPH K55 X-band radar unit, and the evaluation of an MPH Ka-band radar unit begun. The study on the affects of weather on Ka-band vs. X-band Doppler Radar performance should be completed (or near complete).
- c) Statistically validate radar testing approaches – The results of the second quarter tests will be statistically analyzed.
- d) Develop requirements for Ka-band radar meeting requirements of the Court system – Some preliminary conclusions may be made by the end of this quarter.
- e) Examine the state of development for Laser-band Radar – The beginning of testing of laser radar systems is anticipated during this quarter.

3. List of deliverables provided in this quarter by task (product date):

- a) Literature Search – Appendix I of this report was complete on 1/31/07.
- b) First Quarterly Report – was completed on 4/6/07
- c) Monthly reports – It was agreed that meeting minutes would be used in place of monthly reports and were completed on 1/23/07, 2/06/07 and 3/13/07 respectively. This minutes are in Appendix II.

4. Progress on Implementation and Training Activities: Not applicable to this project.

5. Problems/Proposed Solutions: None. Desired evaluation of laser radar units was voluntarily accept as part of this research project.

Total Project Budget	\$49,837.00
Modified Contract Amount:	\$00.00
Total Project Expenditure to date	\$00.00
% of Total Project Budget Expended	0%

Appendix I Literature Search

1. Boric-Lubecke, O.; Lubecke, V.M.; Host-Madsen, A.; Samardzija, D.; Cheung, K., **Doppler radar sensing of multiple subjects in single and multiple antenna systems, [Telecommunications in Modern Satellite, Cable and Broadcasting Services, 2005. 7th International Conference on](#)**, Volume: 1 28-30 Sept. 2005, Page(s): 7- 11 vol. 1.

Summary: Doppler radar life sensing has shown promise in medical and security applications, however the problems of motion artifacts and presence of multiple subjects limit the usefulness of this technique.

2. Ciuciu, P.; Idier, M., **Regularized Doppler radar imaging for target identification in atmospheric clutter, [Acoustics, Speech, and Signal Processing, 2004. Proceedings. \(ICASSP '04\). IEEE International Conference on](#)**
Volume: 5 17-21 May 2004, Page(s): V- 265-8 vol.5.

Summary: We develop a method for the formation of Doppler radar images with enhanced features. This problem, when studied as an adaptive spectral estimation problem, is particularly ill-posed because of the small number of data. Our approach is based on a re

3. Fisher, P.D., **Improving on police radar**, [Spectrum, IEEE](#), Volume: 29 Issue: 7 Jul 1992, Page(s): 38-43.

Summary: The use of lasers, cameras, and advanced signal processing to help isolate individual offenders on crowded highways is discussed. The limitations of the predominant radar in use today, namely down-the-road Doppler-radar.

4. Fisher, P.D.; Pyhtila, J.W., **Timing quantization error in lidar speed-measurement devices**, *Vehicular Technology, IEEE Transactions on*, page(s): 276-280, Volume: 49, Issue: 1, Jan 2000.

Summary:

5. Greneker, G., **Millimeter wave safety warning system for in-vehicle signing**, [Radar Conference, 1997., IEEE National](#), 13-15 May 1997, Page(s): 182-185.

Summary: Georgia Tech Research Institute (GTRI) has developed a millimeter wave safety warning system for in vehicle signing that is soon to be tested for applicability for use in the nation's Intelligent Transportation System (ITS) (formerly IVHS).

6. Heide, P.; Magori, V.; Schwarte, R., **Coded 24 GHz Doppler radar sensors: a new approach to high-precision vehicle position and ground-speed sensing in railway and automobile applications**, [Microwave Symposium Digest, 1995., IEEE MTT-S International](#), 16-20 May 1995, Page(s): 965-968 vol.2.

Summary: Coded 24 GHz Doppler sensors have been realized to perform high-precision non-contact vehicle position and speed measurements. Encoding the radar signal with a spread-spectrum code is the key to a significantly enhanced sensitivity combined with a radar.

7. Kleinhempel, W.; Bergmann, D.; Stammeler, W., **Speed measure of vehicles with on-board Doppler radar**, [Radar 92. International Conference](#), 12-13 Oct 1992, Page(s): 284-287.

Summary: The system configuration of an on-board Doppler radar system is presented which is based on millimeter wave frontends (61 GHz) and digital processing of baseband signals. For the estimation of the Doppler frequency a novel method is used

8. Klugmann, D.; Stephan, R., **Calibration of portable FM-CW Doppler radar profilers with an artificial target**, [Geoscience and Remote Sensing Symposium, 2004. IGARSS '04. Proceedings. 2004 IEEE International](#)
Volume: 6 20-24 Sept. 2004, Page(s): 3953- 3955 vol.6.

Summary: Two portable mono-static FM-CW Doppler radar profiler systems have been calibrated using a continuously rotating corner reflector. The front-ends of both radars apply semiconductors for the generation of the transmitted power.

9. Leeson, D.B.; Johnson, G.F., **Short-term stability for a Doppler radar: Requirements, measurements, and techniques**, [Proceedings of the IEEE](#) Volume: 54 Issue: 2 Feb. 1966, Page(s): 244- 248.

Summary: Short-term frequency stability is an important parameter affecting resolution and range of a Doppler radar. This paper describes system and circuit requirements found in a typical airborne Doppler radar designed for operation in a severe vibration.

10. Rahman, Z.A.; Hasan, W.S.W.; Noor, S.B.M.; Hassan, M.K., **Speed trap detection with Doppler effect**, [Research and Development, 2003. SCORED 2003. Proceedings. Student Conference on](#) 25-26 Aug. 2003, Page(s): 202- 206.

Summary: In this paper, the 8-bit MC68HC11 MCU micro controller is used to receive data speed from Doppler radar speed sensor. Vehicle speeds are detected by Doppler radar speed sensor and then sent to a micro controller.

11. Rasshofer, R.H.; Biebl, E.M., **A direction sensitive, integrated, low cost Doppler radar sensor for automotive applications**, [Microwave Symposium Digest, 1998 IEEE MTT-S International](#), Volume: 2 7-12 Jun 1998, Page(s): 1055-1058 vol.2.

Summary: We fabricated and tested an integrated, low cost, W-band Doppler radar sensor, capable to provide direction sensitive velocity information. The front-end consists of an active integrated antenna in self-mixing operation and a surface-wave coupled, microstrip.

12. Roselli, L.; Alimenti, F.; Comez, M.; Palazzari, V.; Placentino, F.; Porzi, N.; Scarponi, A., **A cost driven 24 GHz Doppler radar sensor development for automotive applications**, [Radar Conference, 2005. EURAD 2005. European](#), 6-7 Oct. 2005, Page(s): 335- 338.

Summary: This paper deals with a low-cost 24 GHz Doppler radar sensor for traffic surveillance. The basic building blocks of the transmit/receive chain, namely the antennas, the balanced power amplifier (PA), the dielectric resonator oscillator (DRO).

13. Westphal, R.; Kessler, A., **35-GHz-Doppler radar for law enforcement agencies in Europe**, [Microwave Symposium Digest, 1988., IEEE MTT-S International](#), 25-27 May 1988, Page(s): 1031-1033 vol.2.

Summary: An experimental program was conducted to investigate the reflectivity of moving motor vehicles using a Ka-band CW Doppler radar, as well as the accuracy of speed measurements as a function of parameters such as antenna polarization, beam ill.

14. Woll, J.D., **Monopulse Doppler radar for vehicle applications**, [Intelligent Vehicles '95 Symposium., Proceedings of the](#), 25-26 Sep 1995, Page(s): 42-47.

Summary: This paper describes an efficient, forward looking, radar system that can be used for vehicle applications including collision warning, collision avoidance and adaptive or intelligent cruise control. A Doppler radar system is described.

Appendix II Meeting Minutes

Ka-band Radar Research Meeting Minutes January 23, 2007

Present: Officer Greg Williams, NJ State Police; Dr. Allan Guida, LTI; and Dr. Allen Katz, TCNJ

1. The objectives of the research project were reviewed. It is desired to evaluate the performance of new Ka-band radar units and their merits relative to the X-band radar units presently in use. There is also interest in the relative performance of laser based radar unit, but such units are only limited to use from stationary positions.
2. Preliminary test plans were discussed. A X-band (currently used) and a test Ka-band radar unit will be mounted in a vehicle and their relative performance evaluated in the field under actual operating conditions. The importance of testing under different environmental condition was raised by Dr. Guida. A discussion of the affect of the environment on laser radar, (particularly multi-path reflections), was discussed.

AI: Dr. Guida will begin an investigation of the affect of environment on laser radar performance.

3. It was noted that there are a number Ka-band radar units made by different manufacturers that are possible candidates for adoption by the State Police. It was recommended that all possible units be evaluated in the study. Dr. Katz requested that the model names of all units under consideration be provided to him. He asked for manufacturer contact information so that he can obtain specifications and technical data on these units. This information will be used to evaluate their relative technical merit.

AI: Officer Williams to provide the information on radar types and manufactures' contact for all Ka-band units under consideration.

AI: Dr. Katz to contact manufactures and obtain required technical information.

4. Draft forms to be used to record data during the testing were reviewed. It was recommended that the forms include a cover sheet indicating: a) the location of the test, b) date and time of the testing, c) the type of unit being tested, d) comments on any unusual conditions and weather. It was suggested that a picture be taken of the area where each test is conducted. It was also suggested that the forms be kept and recorded on a laptop computer.

AI: Officer Williams will develop second draft forms and e-mail them to Drs. Katz and Guida.

5. Possible dates for the next meeting were considered. Dr. Katz said that Tuesday were generally best as he has no classes on this day. Officer Williams will review his schedule and propose a date for the next meeting.

Ka-band Radar Research Meeting Minutes February 6, 2007

Present: Officer Greg Williams, NJ State Police and Dr. Allen Katz, TCNJ

1. Reviewed the car and equipment to be used during the tests. An MPH Ka-band unit was mounted. An X-band unit will be added to make side by side comparisons. A laser radar unit was also available for inspection. The relative size of the units was discussed.
2. Officer Williams reported on his meeting with the Attorney General. Dr. Katz offered to meet with the Attorney General, if this would be helpful.
3. Officer Williams also reported that representatives from MPH (Kevin Willis and District Sales Manager, Ken McClure) will be visiting on Tuesday February 20st at 10 am. Dr. Katz said he could not be present because he is scheduled to be at a conference in Washington on that date. He suggested that Dr. Guida might attend in his place.
4. The revised test forms were reviewed again. Estimated distance will be included on the forms for each test. Test plans were discussed. Radar unit testing will be conducted at the next meeting.

AI status:

AI-1: Officer Williams to provide the information on radar types and manufactures' contact for all Ka-band units under consideration. [Completed].

AI-2: Dr. Guida will begin an investigation of the affect of environment on laser radar performance. [In progress].

AI-3: Dr. Katz to contact manufactures and obtain required technical information. [Manufactures has been contacted. Information has been received from MPH. Greg Williams provided some information on the Stalker unit].

AI-4: Officer Williams will develop second draft forms and e-mail them to Drs. Katz and Guida. [Completed and forms reviewed].

Ka-band Radar Research Meeting Minutes March 13, 2007

Present: Officer Greg Williams, NJ State Police; Dr. Allan Guida, LTI; and Dr. Allen Katz, TCNJ

As of 2/06/2004

1. The recent meeting between Trooper Williams and representatives of Stalker Radar was discussed. Various trades between Stalker and MPH radar products were considered. Stalker provides simultaneous display of both forward and back looking radar returns.
2. Recent test results comparing X and Ka-band radar units were reviewed. Two hundred comparative measurements were taken. The tests were conducted using a Stalker Ka-band radar from a fixed location. Measurements were made in both rain and snow weather conditions. The testing showed generally close agreement between the X and Ka-band measurements, but there were some discrepancies. Drs. Katz and Guida will perform a statistical analysis of the results. It was noted that data is needed for fair weather operation under both fixed and in motion conditions. Also comparison data should be taken with an MPH Ka-band radar unit. It was decided that Dr. Guida would observe and assist during testing under moving conditions.
3. It was decided that the next meeting will be scheduled for March 27th. At this meeting the first quarter report will be discussed.

Ka-band Radar Research Meeting at DOT Minutes, March 13, 2007

Present: Officer Greg Williams, NJ State Police; Mr. Edward Kondrath, Bureau of Research, NJ Dept. of Transportation; and Dr. Allen Katz, TCNJ

This meeting was called by Edward Kondrath, Project Manager for the Bureau of Research to review the quarterly report. Due to a misunderstanding the report was not ready. Allen Katz believed this meeting was to discuss the contents of the report in support of the preparation of the final report.

It was agreed that the first quarterly report would be submitted by April 9th and the remaining quarterly reports by the last day of the quarter. The second quarterly report will be due on June 30th.

Edward Kondrath asked for monthly reports to be kept informed of research progress during the quarter. It was noted that regular project minutes were being held with written minutes documentation the project progress. It was agreed that copies of these meeting minutes could be sent in place of the monthly reports. The minutes for meetings during the first quarter will be included in with this quarterly report. All future meeting will be copied to Edward Kondrath.

The status of the project was briefly discussed. 200 measurements comparing Ka and X-band radar units have been taken and statistically analyzed. The evaluation of fixed laser radar units has been added to the project tasks.

Edward Kondrath suggested that TCNJ students be involved in the project if appropriate. Allen Katz said that this was appropriate and he would arrange for more student involvement.

Edward Kondrath also stressed the importance of making clear the benefits of the research work in the project report. Officer Greg Williams will contact the State Attorney General's office to obtain cost-benefit figures.

As of 2/06/2004

The impact of the addition of the laser radar test work was discussed.